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INVESTIGATION OF THE SIERRA ANCHA WATERSHEDS WITH RESPECT TO ADJUSTABLE CHANNEL MORPHOLOGY

by

Tim J. Ward, Professor
Department of Civil, Agricultural, and Geological Engineering
New Mexico State University
Las Cruces, New Mexico

TECHNICAL COMPLETION REPORT
Account Number 01423972
Cooperative Agreement No. 28-C2-665

September 1995

New Mexico Water Resources Research Institute
in cooperation with

USDA Forest Service
Rocky Mountain Forest and Range Experiment Station
Stream Systems Technology Center

and

Department of Civil, Agricultural, and Geological Engineering
New Mexico State University

The research on which this report is based was financed by the USDA Forest Service and the U.S. Department of Interior, Geological Survey, through the New Mexico Water Resources Research Institute.

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ABSTRACT

Alluvial channels are shaped by forces and processes that are controlled by a complex interaction of geology, soils, vegetation, climate, and human influence. Channels will tend to adopt a shape which balances streamflow energy and the material forming the channel. A paradigm of channel morphology is the effective discharge or that discharge that transports the largest amount of sediment in the long-term under current climatic conditions and may be thought of as the channel maintaining flow. The effective discharge is believed to be closely related to bankfull discharge. Much of what is know about channel shape and form was developed from studies of sand-bed alluvial streams. In upland watersheds, materials comprising the stream bed and banks are much coarser and require much more energy to be transported. What is needed is a better understanding of the forces and processes controlling channel shape in upland watersheds.

In this study, streams in the Sierra Ancha Experimental Watershed in central Arizona were investigated to determine if there was a discernable relation between channel shape and influencing variables including bed slope, size of channel materials, and discharge volume. Historic data from USDA Forest Service files were collated and converted to electronic form in order to analyze the discharge characteristics of the eight sites investigated. The office studies were augmented by field work to measure channel shape, slope, and bed and bank materials. The largest watershed supplying a channel site was less than 1000 hectares in area. Only one site could be identified as having an alluvial channel, all the other channels were controlled by bedrock or large boulders. It was concluded that, at least for the sites investigated in this study, effective discharge was not an applicable concept.

During this study, a large body of data was gathered, collated, converted to electronic form, and analyzed. These data should be useful in future studies related to water yields, flood flows, land use effects, and sediment transport analyses. The updated data for Upper Parker Creek is a new addition which has not yet been analyzed to determine the water yield characteristics of that watershed. Better estimates of yield from upland watersheds such as Parker Creek and Pocket Creek will become more important as greater pressures are placed upon water resources in the west.

INTRODUCTION

General

A key element in watershed management is the protection and efficient use of the water resources available internally and externally to the watershed. In large river basins, these resources are generated from precipitation over the basin, transbasin diversions, or through mining of ground water. Small upland watersheds play an essential role in providing the internal sources of water for the large river basins. This is particularly important in the arid west where the upland watersheds are located in the zones where there is a surplus of water above the needs of vegetation. This surplus or runoff leaves the watershed to enhance the available water resources further downstream in the basin where precipitation is usually less than potential and actual evapotranspiration. Efficient transmission of the surplus water from the upland watersheds to the downstream basin is critical to meet the ever increasing demands on this resource.

However, efficient transmission does not mean that the watersheds and channels should be engineered into an artificial state of impervious surfaces and straight, lined canals. Although such methods are used for water harvesting schemes on small areas, such an approach would leave upland watersheds unable to sustain themselves through the natural processes of infiltration, subsurface flow, evapotranspiration, and, subsequently, runoff. Such a scheme would also create havoc with the important processes involved in riparian zone surface water-ground water-vegetation interchange. Resource managers recognize that the destruction of one ecosystem in order to benefit another is short sighted and, in the long run, harmful to the original beneficiary.

In order to adequately address the demands for water resources while at the same time providing for sustainable ecosystems, the different components of the land-water-vegetation system must be investigated and analyzed. One important component in the system is the channel network. The channel network is the result of interacting processes and forces related to geology, climate and weather, and vegetation. These elements interact over long time periods to come into an equilibrium state. Channel networks in younger terrain may not yet have reached a state of equilibrium, whereas those in older terrain may have gone through several equilibrium periods. Although there is variability within an equilibrium state, it is not until the system is perturbed by natural or human caused events that it transitions or jumps into a different state. An example from alluvial river mechanics is the transition of a meandering system into a braided system by a large influx of sediment from a landslide. The braided nature of the river may exist for several kilometers downstream of the landslide before the existing forces equilibrate with the added sediment load and the river returns to a meandering state. The effected reach may over time return to the meandering state naturally. In some cases, human intervention is needed to modify the channel so that it reverts to a meandering form.

Channels which are in a state of equilibrium are a reflection of the balance between the different watershed components. Development of water resources may perturb the balance by adding excess water to the channel in the case of transmountain diversions or by removing water from the channel through out-of-watershed diversions. Conversion of vegetation types or changes

in vegetation structure or diversity in order to increase water surplus can also have an impact on the channel system beyond the addition of more water. Such changes can affect riparian vegetation, stream bank stability, sideslope erosion, and stream temperature which would further reduce channel efficiency, increase evaporation, and produce unwanted sedimentation problems.

In the case of out-of-watershed diversions for watersheds larger than those investigated in this study, an important consideration is the reduction of channel carrying capacity and thus the efficiency for transmission of water. This reduction would be a result of sediment infilling from the side slopes and by encroachment of vegetation. Although such changes have been postulated, it has been difficult to demonstrate the effects of the reduced capacity. The key hypothesis is that channels will adjust to the imbalance in the long term processes and forces that have shaped them over the centuries. However, diversions from upland watersheds in the west have only been systematically conducted for periods on the order of 100 years. This length of time may not be sufficient to produce the effects that are hypothesized, if in fact they do occur. For smaller watersheds, similar to those in the study, diversions would be on a much smaller scale for local agriculture and domestic use. Land use such as timber harvesting and grazing and natural hazards such as fire have a more profound, but perhaps short term effect, on water yield and consequent channel adjustment.

Not all segments of the channel system in upland watersheds can change when an imbalance of processes or forces occurs. Some segments are founded in bedrock and are not subjected to infilling or vegetation encroachment. Conversely, those segments founded in alluvial materials may change very rapidly, particular when subjected to high discharges. Therefore, it is not meaningful to characterize the entire channel system of a watershed by select segments. It is important from the standpoint of understanding watershed health, though, to identify and analyze those channel segments which may respond to an imbalance of processes and forces by rapidly changing form or slowly transitioning into a new state.

Although there is a large body of research on the morphology of sand bed rivers and streams, there has been little developed about form and process in gravel and cobble bed streams. This has arisen from historical reasons. The larger streams and rivers are the centers of trade, cities, and transportation and have been subjected to scrutiny for much longer periods. The changes in sand bed alluvial streams are also more rapid and much easier to detect in a historical perspective. Gravel and cobble bed streams, on the other hand, require more energy to move the larger materials and therefore adjust much slower. However, the laws of physics are the same no matter what type of channel is being considered so understanding of form and process in sand bed channels can be transferred after, considering the different energy setting, to gravel and cobble bed streams. If form and process are truly transferable between channel types and across scales, then observations on channel morphology should hold when one looks at different channels in different settings. A primary hypothesis of this study is that processes acting in small watersheds (less than about 25 square kilometers or about 10 square miles) should manifest themselves by creating channel morphology comparable to the channel morphology in larger watersheds or channels. This hypothesis is examined by studying channel morphology and controlling variables in selected upland watersheds in Arizona.

Goals and Objectives

The original goal of this cooperative agreement (study) was to study selected watersheds in Arizona to establish effective discharge at historical and existing stream gaging stations. Effective discharge is the discharge at which the energy conditions are sufficient to maintain a channel morphology reflecting the overall nature of the channel and the contributing watershed. Harrelson, et al. (1994) state that the effective discharge is "...the flow that transports the largest amount of sediment in the long-term under current climatic conditions and may be thought of as the channel maintaining flow" (page 33). For alluvial channels, the effective discharge closely corresponds to the bankfull discharge. If the effective discharge could be identified for the channels in the study, then the resultant information would be useful in developing relationships between effective discharge and channel characteristics such as sediment transport, channel cross-sectional shape, and channel maintenance flows for small arid and semi-arid Southwestern watersheds.

Objectives: The specific objectives of this study were to:

1. Review the data assembled by the USDA Forest Service personnel (including Ron Hibbert, Lowell Rich and Jerry Gottfried) and secure it in a fashion to provide ready access for additional studies of channel maintenance and other instream issues.

2. Review the specific long-term effective discharge versus bankfull flow characteristics at watersheds selected from one or more of the following USDA Forest Service (USFS) study areas: Thomas Creek, Beaver Creek complex including Woods Canyon and Bar-M, Three Bar, or the Parker, Pocket, and Workman Creek gauge complex at Sierra Ancha.

3. Develop channel geomorphic versus streamflow relationships and to identify key factors, tied to the assumptions of Forest Service Handbook 2509.17 chapter 30, that determine channel morphology for basins of this size.

4. Describe areas requiring further study and research along with the best current scientific indications of how to proceed.

Approach

The goal of this study was attained by an integrated approach involving office and field work. The office work focused on the identification, collation, analysis, and presentation of the existing data for the selected watersheds. The field work focus on data collection of information related to stream characteristics. Specifically, the approach contained the following elements:

Office work: The in-office part of the study consisted of the following tasks:

1. Selection, through consultation with USFS personnel, of target watersheds and stream gauging sites. Particular attention was paid to those sites which were previously studied by Ron Hibbert et al.

2. Search of storage areas containing historic files to identify existing data and other information, such as field notes and photographs, related to the target watersheds.

3. Consolidation and isolation of the existing files to avoid possible dispersal during reorganization activities.

4. Conversion, when possible, of the existing paper based streamflow records into electronic media targeted for MSDOS based microcomputers.

5. Analysis of the streamflow records using appropriate hydrographic and statistical methods which may include time series analysis, flow-duration relationships, cumulative mass curves, peak discharge distributional analyses, intergauge correlations, hydraulic parameter identification, and other techniques as dictated by the existing data and anticipated field data.

6. Development of a prototype data base for presentation, manipulation and display of the existing data for use by future researchers.

Field work: The in-field portion of the study consisted of the following tasks:

1. Visit potential study sites with USFS personnel to determine which should be used for this study.

2. Conduct field data collection at the selected sites. The field data collection will include: selection and marking of permanent channel cross sections, identification of "bank full" flow levels, measurements of the cross sections, measurements of stream longitudinal profile, Wolman pebble counts at the selected stream sections, bulk sampling of channel and bank materials for laboratory analyses of grain size distribution, and securing a photographic record of the sites, cross sections and sample points.

The field data were subsequently analyzed using standard procedures for processing and presenting the information.

Modification of Objectives

The field work in May of 1994, described in the RESULTS section later in this report, made it clear that adjustable channels in watersheds of the size investigated in the study area were almost nonexistent. Therefore, the focus of the study was modified to provide for a better understanding of the characteristics of upland channels and the hydrology which affects them. More effort was expended on the conversion and reduction of paper data to electronic form and electronic form to more easily manipulated data bases. Specifically, punched card data were converted to electronic form, cleaned and processed; paper data were converted to electronic form as spreadsheets; and the converted punch card data, and existing data of the same type provided by the USFS, were processed

and converted to spreadsheet data bases. These converted data and spreadsheet data bases will be useful in further studies of the watersheds by USDA personnel or their cooperators.

An additional section, not required in the original cooperative agreement, was added to this report which describes work in progress by Bathurst and Ward (in progress) related to effective discharge and sediment transport in gravel and cobble bed streams. Because it is work in progress at the time of this report, the results should be considered preliminary.

METHODS

Sites

Watershed Selection

The sites selected for analysis through consultation with the USFS were the Parker, Pocket and Workman Creek watersheds in the Sierra Ancha Experimental Forest north of Globe, Arizona. These watersheds were first instrumented in the mid to late 1930's. Records from some of the watersheds persisted into the 1980's. The in-field portion of this study was conducted at each of the watersheds selected.

In-office

The in-office portion of this study was conducted at the former offices of the USFS Rocky Mountain Forest and Range Experiment Station located on the Arizona State University campus in Tempe, Arizona. The in-office portion was conducted in advance of the USFS planned move to new offices in Flagstaff, Arizona. Data from the selected watersheds were reviewed and secured prior to the move. Some critical data were sent to New Mexico State University (NMSU) by the USFS and this author for further analysis and safekeeping during the duration of the study.

Field Methods

Field work was conducted using standard techniques such as recently detailed by Harrelson et al. (1994). Each gage site was visited and inspected to determine if adjustable channels were present either immediately upstream of the gage. Downstream locations were dismissed from consideration because the gaging structures at the sites, concrete walls with critical flow control measurement sections, trapped a significant volume of sediment keeping it from the downstream channel. Where adjustable channels existed (two sites), measurements of the cross sections, measurements of stream longitudinal profiles, Wolman pebble counts, bulk sampling of channel materials for laboratory analyses of grain size distribution, and field notes were collected. These data were reduced and analyzed at NMSU.

Office Methods

Data was reduced and analyzed using standard laboratory, numerical and statistical techniques. The SAS (SAS Institute 1989) software on the NMSU computing system was used to perform the statistical analyses. Programs were written in FORTRAN to read the electronic stage data, provided by the USFS for Workman Creek and for Parker and Pocket Creeks as converted from punch card data by the author, and process them into daily discharges and find the instantaneous peak value for the year. Sieving of bulk channel samples was performed following standard procedures (e.g. Das (1994)). The data was also analyzed using the plotting and numerical capabilities of spreadsheet software.

RESULTS AND DISCUSSION

Description of Watersheds

The Sierra Ancha watersheds were established by the USFS in the Sierra Ancha Experimental Forest during the mid to late 1930's as part of an effort to understand the hydrology of upland watersheds in the arid and semi-arid southwest. The gaging sites were established to measure water flow and not sediment discharge. The sites are located 48 km north of Globe, Arizona, and north northeast of Theodore Roosevelt Lake. The watershed sites are in the Pleasant Valley Ranger District of the Tonto National Forest and can be reached from Arizona State Highway 288. The watersheds share the drainage divide with the Sierra Ancha Wilderness. All of the watersheds are located on the US Geological Survey (USGS) 7.5 minute Aztec Peak, Arizona (provisional edition 1986), 1:24000 quadrangle map. This quadrangle is almost directly in the middle of Arizona between 110°52'30" and 111°00' west, and 33°45' and 33°52'30" north. The map presented in Figure 1 was taken from USFS files and shows the general outlines of the watersheds and their relation to one another. This map predates the existing 7.5 minute quadrangle so there is a bit of a discrepancy in the watershed areas measured in this study. However, the general shape is the same. Table 1 lists the physiographic measurements for the watersheds taken from the 7.5 minute topographic map and compares it to information from USFS files and Hibbert and Gottfried (1987) who reported on the Workman Creek subwatersheds. Note that the areas determined for the Workman Creek subwatersheds in this study are different than those presented by Hibbert and Gottfried (1987). The areas used by Hibbert and Gottfried were based on intensive on-ground surveys conducted during the period of 1936 to 1938. In subsequent analyses of the Workman Creek main dam data, a drainage area of 440 hectares was used to calculate depths of runoff even though an area of 456 hectares was measured. The overall channel lengths were measured from gage location to the fartherest point on the watershed boundary to which the main channel was extended. The change in elevation is from the gage site to the fartherest point. The channel slope is the change in elevation along the main channel divided by the main channel length to the watershed boundary. The channel slopes vary considerable from point to point along the channel. The slopes in Table 1 indicate the overall steepness of the channel system.

The geology, soils, and vegetation for Workman Creek have been detailed by Rich and Gottfried (1976) and Hibbert and Gottfried (1987). Their descriptions are pertinent to the entire area. Bedrock is composed of quartzites, sandstones, and other sedimentary rocks with local intrusions of fine-grained igneous rocks such as basalt. Soils derived from these parent rocks range from clay to loams. Vegetation varies from mixed conifer (Ponderosa pine, Douglas fir, and white fir) at the higher elevations to oak and chaparral at the lower elevations.

In-office

Three trips were made to the USFS offices in Tempe. The bulk of the files were in paper form. Time-stage data for the Workman Creek gages had previously been converted to electronic form and stored on 3.5" floppy disks. The headers on the Workman Creek data sets were not consistent and have been changed by the author.

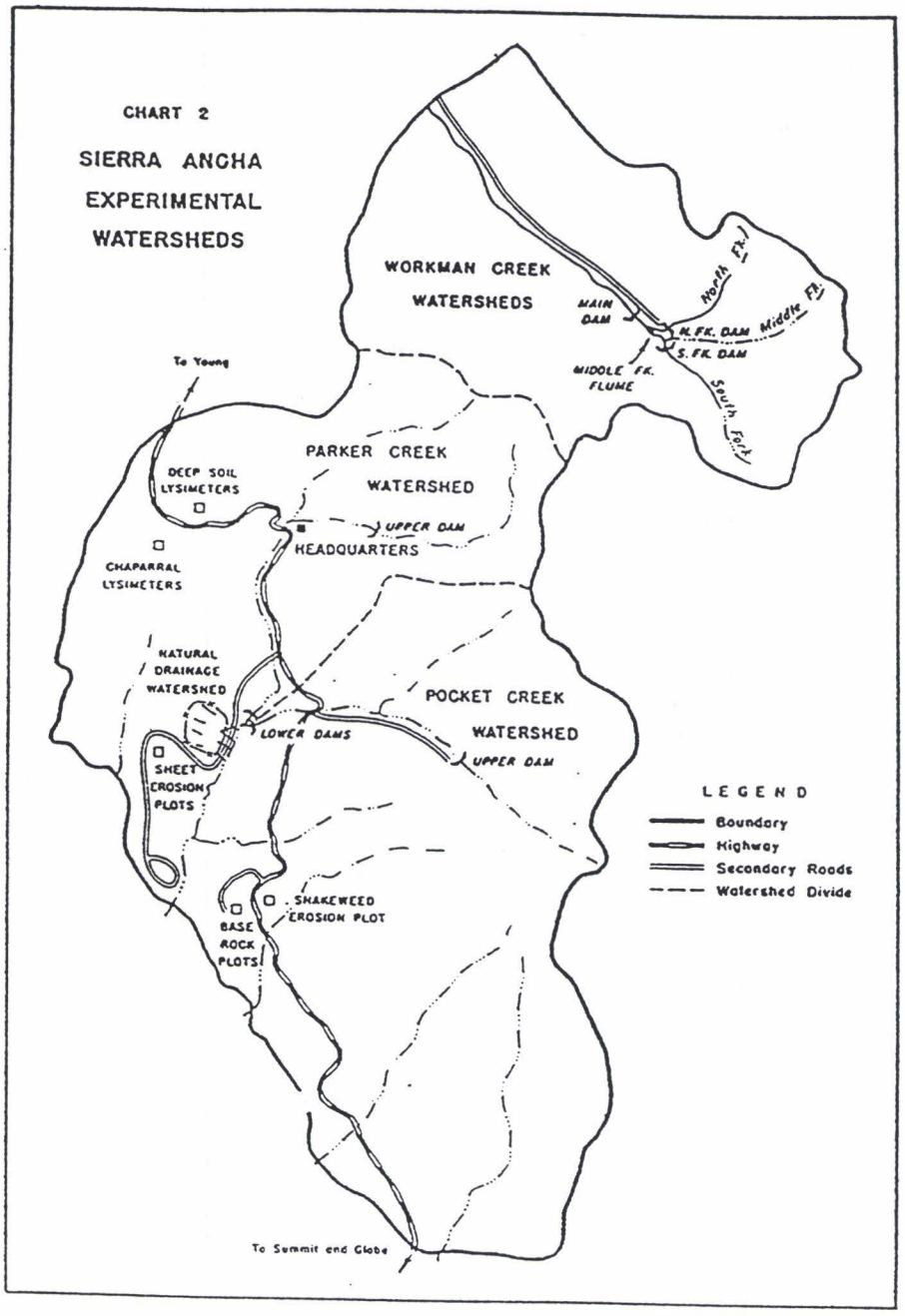
Table 1. Characteristics of the Sierra Ancha Watersheds

Site	Gage Elev, m	Area, ha	Area from Previous Studies, ha	Channel [1] Length, m	Elevation [2] Diff., m	Channel [3] Slope
Workman Cr. Main Dam	2012	456	440	2520	210	0.083
Workman Cr. North Fork	2049	97	100	1685	262	0.155
Workman Cr. Middle Fork	2049	156	211*	2069	256	0.124
Workman Cr. South Fork	2049	116	129	2040	174	0.085
Upper Parker Cr.	1659	269	283	2971	518	0.174
Lower Parker Cr.	1354	962	988	6530	823	0.126
Upper Pocket Cr.	1622	363	366	2213	500	0.226
Lower Pocket Cr.	1354	826	842	4982	771	0.155

1 - From outlet to watershed divide
2 - Between outlet and point on watershed divide to where channel is measured
3 - slope = difference in elevation/channel length
* - Area between confluence and Main Dam is included.

Data were kept in two locations primarily, in a set of file drawers on the second floor and in the vault. There were five (5) file drawers containing Sierra Ancha data in paper form. Each drawer contained data for a separate watershed or site as detailed below (years are water years):

Figure 1. Outline Map of the Sierra Ancha Watershed



Workman Cr.:	Main	1938-1980 Pick Point Data and Summaries
	North Fork	1938-1980 Pick Point Data
	Middle Fork	1952-Feb. 5, 1980 Pick Point Data
	South Fork	1938-1980 Pick Point Data
Upper Parker Cr.:	1934-1972, 1977-1980 Pick Point Data and Summaries	
Lower Parker Cr.:	1935-Aug. 1953, 1956-1960, 1962-1963 (partial) Pick Point Data 1935-1952, 1956-1960, 1962-1963 (partial) Summaries	
Upper Pocket Cr.:	1936-1965 Pick Point Data 1947, 1954-1972 Summaries	
Lower Pocket Cr.:	1935-1942, 1946-1962 Pick Point Data 1935-1942, 1946-1952, 1958-1960, 1962 Summaries	

The gaging sites had 90° v-notch and Cippoletti (broad crested) weirs to measure low and high flows, respectively. The gage heights were recorded on paper charts. When the charts were brought back to the laboratory, the chart readers noted the heights and corresponding times when breaks occurred in otherwise linear traces of heights. All charts had the midnight height recorded. These break points are called pick points (as listed above). For a water year, the number of pick points was easily in the hundreds and often exceeded 1000. Before the pick point data were stored electronically by the Forest Service, they were screened to eliminate small changes in stage. Each gage height was converted to a discharge and the volume of water passing the gage in the midnight-to-midnight, 24-hour period was calculated. These daily values or volumes were converted to inches of depth for the watershed and entered on the summary sheets referred to above. The summary sheets were tabulated for each month and the total depth of runoff for the month and the 12 month water year were calculated. As the list above shows, not all the pick point data were converted to summary sheets. These summary sheets were converted from the paper record to a spreadsheet format for this study. In some cases, data were added to the sheets after additional analysis and processing. The file cabinets also held numerous old photographs of the sites before and after gage installation and other documents describing activities which took place on the watershed.

The vault held the original strip charts, punched cards, and weather data, among other items. The data as found in the **vault** were classified as follows:

Workman Cr.:	Main	1980-1983 Charts (up to 1979 on disk)
	North Fork	Charts through 1980 (up to 1979 on disk)
	Middle Fork	1980-1983 Charts (up to 1979 on disk)
	South Fork	1980-1983 Charts (up to 1979 on disk)

Upper Parker Cr.:	1934-1972, 1977-1986 Cippoletti Charts 1934-May 1980 V-notch Charts
Lower Parker Cr.:	1935-1963 (partial) Cioppoletti and V-notch
Upper Pocket Cr.:	1936-1972 Cippoletti Charts 1936-1968 V-notch paper Charts June 6, 1968 - Jan. 4, 1973 V-notch punched tape
Lower Pocket Cr.:	June 1935-1963 (partial), 1969-1970 Charts

Not all of the charts found in the vault had been marked for pick points. This was evident for Workman Creek subwatersheds and the Upper Parker Creek site. Consistent, accurate reading of the charts will require someone who has familiarity with the way the data were collected. Addition of the Workman Creek Main Dam and the Upper Parker Creek sites would be helpful in filling the gap into the 1980's in the first case and into the 1990's in the second. This author attempted to read the charts but quickly was confused as to what the they were showing. The vault also held data from other watershed studies which was not part of this effort.

Punched cards were found in the vault for the Parker and Pocket watersheds. These data were shipped to NMSU and were subsequently converted to electronic form. Conversions were checked by matching recorded peak flows listed on paper with peak flows as determined from the punched card/electronic data. The Workman Creek data in electronic format had been converted to equivalent gage heights for the V-notch weir by the Forest Service. The working equation for the 90° v-notch weirs was:

$$Q = 2.54\ H^{2.5} \qquad (1)$$

where Q is discharge in cubic feet per second and H is gage height in feet. Because of the low discharges normally found in the channels, most gage heights were on the order of about 0.1 feet. The Cippolletti or broad-crested weir was used when the flow exceeded the capacity of the V-notch weir alone. The general equation for the Cippoletti weir was:

$$Q = a\ (H-b)^{1.5} \qquad (2)$$

where a is a parameter and b is the height at which the capacity of the V-notch weir is exceeded. As the depth of flow increased, then length (weir width) corrections were used to modify the Cippolletti measurements as:

$$Q = c\ L\ (H-d)^{1.5} \qquad (3)$$

with

$$L = f - g\ (H-b) \qquad (4)$$

where c, f and g are parameters, and d is the height at which a length correction L is needed. The general equation for an installation would then be, combining (1), (2), and (3):

$$Q = 2.54\ H^{2.5} + a\ (H-b)^{1.5} + c\ L\ (H-d)^{1.5} \qquad (5)$$

Values of Q found with Eqn. (5) were converted back to equivalent stages (this was done by the USFS) through Eqn. (1) for the Workman Creek electronic, Upper Parker punched cards, and Upper Pocket punched cards. The punched card data for the Lower Parker gage were in the form as needed by Eqn. (5). Both original gage height and converted gage height data sets were created for the Lower Parker site. Because of slight differences caused by round off errors in conversion, the original data were used in the verification of the paper data. The punched card data yielded the following electronic data sets:

Upper Parker Cr.:	1955 partial 1956-1967 complete
Lower Parker Cr.:	1956-1959 complete 1960 partial
Upper Pocket Cr.:	1954 partial 1955-1962, 1966 complete

The punched card data for Upper Pocket Creek did not always start on October 1 and end on September 30 of a water year. It appears that the periods of no flow over Spring-Summer-Fall seasons were excluded to avoid repetition of zeros. Therefore, the data were assumed to be complete for a water year if the beginning and ending values were zero. The yearly water yields were checked against the paper records and verified that this was the case. The 1960 partial record for the Lower Parker site is also very close to the entire yearly record.

In order to determine the amount of time needed to enter data, selected pick point data sheets were shipped to NMSU for processing by the author. The site selected for this effort was Upper Pocket Creek because it did not have complete summaries for several years before 1954. The pick point data sheets also contained the hand calculated daily water yields and accumulations. The monthly data were tabulated from the accumulated values for water years 1937-1953, except for 1947 which already existed. In addition the pick point data for the individual gage height values, along with the corresponding dates and times of occurrence, were entered according to the format as found on the punched card data. This was done for the selected water years of 1941, 1944, 1947, and 1950-1952. Two people were assigned to this task, one to read and one to enter. The monthly summary data required approximately 10 hours (total person hours) whereas the gage height data required 82 hours to read and enter. One person doing this task would require about 2.5 times the hours or about 115 hours based on the author's experience. It is estimated that there are still another 102 data-years of chart or pick point data which could be entered: 16 for Workman Creek subwatersheds, 14 for Upper Parker Creek, 23 for Lower Parker Creek, 22 for Upper Pocket Creek, and 27 for Lower Pocket Creek.

Based on the experienced from the Upper Pocket Creek data entry, the data entry would take a minimum of about 35 person weeks using a read and enter team, i.e. about 4 to 5 months. If the data input was made more efficient, then time required would drop. Conversely, if the data were more difficult to acquire as might be the case with the chart data, then the time would take longer.

The USGS occupied the Upper Parker Creek site from November 16, 1985, through September 30, 1992. Those data in values of average daily discharges in cfs were acquired in electronic form and integrated into the data base.

In-office Data Availability

Data which have been processed during the in-office portion of this study are listed below. These data can be provided on floppy disk if arrangements are made with the USFS which controls access. These data include:

Workman Cr.: Main	1939-1979 Time-gage height pick point data
	1939-1979 Daily flows in cfs-hours and average daily cfs
	1939-1979 Spreadsheets in the same form as USGS average daily flow files
	1939-1979 Spreadsheets in the same form as the USFS summary sheets as derived from the above spreadsheets and not copied from USFS files
Upper Parker Cr.:	1955 partial, 1956-1967 complete Time-gage height pick point data
	1955 partial, 1956-1967 Daily flows in cfs-hours and average daily cfs
	1955 partial, 1956-1967 Spreadsheets in the same form as USGS average daily flow files
	1934 partial, 1935-1980 complete, 1986 partial, and 1987-1992 complete Spreadsheets in the same form as the USFS summary sheets derived from the USFS paper sheets and the USGS data files
Lower Parker Cr.:	1956-1960 Time-gage height pick point data
	1956-1960 Daily flows in cfs-hours and average daily cfs
	1956-1960 Spreadsheets in the same form as USGS average daily flow files
	1935-1963 Spreadsheets in the same form as the USFS summary sheets copied from USFS files, some years are incomplete
Upper Pocket Cr.:	1954 partial, 1955-1962, 1966 complete Time-gage height pick point data
	1954 partial, 1955-1962, 1966 Daily flows in cfs-hours and average daily cfs
	1954 partial,1955-1962, 1966 Spreadsheets in the same form as USGS

average daily flow files
1937-1972 Spreadsheets in the same form as the USFS summary sheets copied from USFS files, complete

Lower Pocket Cr.: 1935 incomplete, 1936-1952, 1953 incomplete, 1958-1962 Spreadsheets in the same form as the USFS summary sheets copied from USFS files

The spreadsheets are contained in electronic data files. A listing of the files is presented in Appendix I for the sites.

In-Field Studies

During the third week of May 1994, a field study was conducted at the Sierra Ancha Experimental Watershed. The focus of the field study was the collection of information related to channel morphology. Of particular interest were:

1) Location and measurement of cross sections,
2) Measurement of surface sediments via Wolman pebble counts,
3) Sampling of sediments for subsequent laboratory analysis,
4) Measurement of stream longitudinal slope.

Expectation and realization are two different things, as the in-field measurements summarized in Table 2 indicate.

Table 2. Type and Number of Samples Collected for Sierra Ancha Channels

Site	Cross-Sections	Pebble Counts	Sediment Sample
Lower Parker Creek	3	3	3
Upper Parker Creek	1	2	2
Lower Pocket Creek	1	2	2
Upper Pocket Creek	1	1	1
Workman Creek, Main	1	2	2
Workman Creek, North Fork	-[1]	-[2]	-[2]
Workman Creek, Middle Fork	-[1]	1	1
Workman Creek, South Fork	-[1]	-[3]	1

1 - Channel conditions precluded measurements
2 - No particles > 10 mm deposited or no deposits
3 - Only particles < 10 mm in deposit

A discussion of each gage site follows in order to indicate channel conditions observed during the field study. Only one channel, Lower Parker Creek, showed signs of an adjustable bed.

Lower Parker Creek

The Lower Parker Creek site had as stream channel which could be considered to be adjustable over distances greater than 100 feet. The gage site is located at the point where the bedrock controlled depositional zones upstream join the steep walled gorge downstream. The upstream areas have zones of deposition which have definitely been reworked by the stream. It is in these zones that the adjusting channels have formed. All of the anticipated measurements were taken at this site. One exception, here as elsewhere, was the measurement of a longitudinal survey from the gage site through the cross section locations. Such profiles were impossible to collect in this size of stream because of channel vegetation, step-pool sequences, large organic debris, and huge boulders. However, in the depositional zones above the Lower Parker Creek site, it was possible to measure a profile at the cross sections. For the channels in the Sierra Ancha Watershed, the energy slope is controlled by the topographic channel slope and the large roughness elements (debris and boulders) in the channel. Localized measurements of channel slope may be misleading with respect to the overall potential energy conditions in the system.

The Lower Parker Creek site did contain areas where discharge formed channels did exist. Cross-sections were measured in the area nearest the gage and below tributary side channels. The location of the cross sections was in an alluvial zone with bedrock walls. The entire width was about 20 feet (6.1 m) . The overbank area (outside of active channel) were vegetated, heavily in some places, and did show evidence of former channels. The channel depths (below top of bankfull height) ranged between 1 and 2.5 feet. The channel slope measured over a distance of 242 feet was 0.03.

The largest "pebble" at the measurement location was 510 mm. A small to medium boulder. Most surface material was larger than medium gravel (10 mm +).

Upper Parker Creek

The Upper Parker Creek site can be characterized as having a channel with a bedrock bottom. Channel banks vary locally with bedrock outcrops, large boulders, and alluvial and colluvial materials being common. Fluvial deposits occur where large boulders or large organic debris have formed dams and subsequent step-pool sequences. There is no channel slope which could be characterized as typical. At the one section where sediment was collected, the channel was constrained between banks of large boulder/soil material. The channel was 20 feet wide, close to rectangular and had a maximum depth between the banks of five feet. The largest "pebble" that appears to have moved at least once in the section had an intermediate axis of 1200 mm, a large boulder. Channel slope was impractical to measure because of the step-pool sequence and the amount of debris in the channel.

Lower Pocket Creek

The Lower Pocket Creek site has a very short reach of alluvial deposition above the gage before the channel is joined by two other tributaries and the main channel enters a bedrock canyon. A section was measured in the alluvial area. The total alluvial zone was about 30 feet wide. The active channel width was 18 feet (5.5 m). Maximum bankfull depth was about 20 inches. The largest pebble was 640 mm, a medium boulder. A channel slope over a very short section (59 feet) was measured as 0.02 (2%). This slope is highly localized and is most likely not indicative of the channel overall.

Upper Pocket Creek

The Upper Pocket Creek channel is heavily overgrown above the gage site. The channel is typically constrained by the steep sidewalls of the canyon which contain large and very large boulders. Upstream of the gage site, the active channel has moved around from one position to another. The sediment sample was collected at a section which was 12 feet wide, fairly rectangular, and had a depth of 19 inches. The slope in this area was about 3% based upon a short distance estimate. The largest "pebble" in the section was 390 mm, a small boulder.

Workman Creek, Main Dam

Workman Creek, like Parker and Pocket Creeks, can be characterized by large boulders and debris controlled depositional zones, bedrock controlled channel bottoms, and boulder embedded banks. At the section where the sediment sample was collected, the channel was 32 feet wide with 30 inch high banks. Twenty feet upstream, the water flowed between, over, and through a section choked with large boulders and debris. The largest "pebble" measured was 890 mm, a medium boulder. One interesting observation at this site is the amount of windthrow which has occurred during the last year. In fact, two medium sized trees which had once stood on the south (left) bank of the creek are now laying in the backwater area behind the dam and on the measurement structure itself.

Workman Creek, The Three Forks

The three forks of Workman Creek above the main dam, North, Middle, and South, all have unique channels. The North Fork has a very stable, vegetation covered channel with water flowing through large rocks and under the vegetation. No discernable channel was apparent. A unique feature of this channel is that there are very few trees near its bank for a long distance upstream. This is the reason that the North Fork is devoid of woody (organic) debris induced step-pool sequences. Very little sediment has been deposited behind the V-notch weir structure. The Middle Fork does have woody debris and step-pools. Very little sediment is trapped behind the structure because it is a V-shaped flume and not a weir requiring a back water.

The South Fork channel is also a debris choked stream. A very unique situation was observed at this site, there were no surface cobbles or boulders deposited behind the structure. In

fact, the largest particle found in a sediment sample was about 20 mm in size. Most of the material was fine gravel and smaller. The reasons for this distinct difference in trapped sediment was unclear. There were some deposits with larger particles upstream, but as to why such particles were not observed at this site is not apparent.

In general, the stream channels in the Sierra Ancha Experimental Watershed are not self adjusting under typical conditions. The size of the bed material, large boulders and organic debris, and bedrock controls mitigate against easily adjustable beds and banks. The concept of a "typical" cross section and longitudinal slope are not relevant to these types of channels. Channel configuration changes on length scales of less than 100 feet, as does channel slope. Although there are some, but very few, isolated alluvial zones where self-formed channels exist, these zones are not typical of the stream. A more important indication of channel and watershed activity are the sizes of sediment being transported in the streams. At most gage sites, excepting two, the sediment deposits are composed of every size from boulders to very fine sand.

Cross-section Data

Detailed cross-sections were measured only at Lower Parker Creek and Lower Pocket Creek. For the other sites, only bankfull width and depth to bank full height were recorded. The detailed data were plotted then planimetered to derive relationships between cross-section depth, area, and top width. This was done to see if there was any similarity between the sections. Figure 2 is a plot of the data for cross-sectional area and depth. The relationship is quite good and can be fit with a power equation as:

$$A = 6.79\, d^{1.85} \qquad (6)$$

where A is area in square meters and d is depth in meters above the lowest point. The R^2 value of this equation is 0.967 based on the logarithmic transforms. Similar relationships were derived for the other variables; for each cross section and for all cross-sectional data lumped together. The parameters are listed in Table 3 for comparison purposes. For the sections measured, the data all seem to be compatible between sections indicating a common response of the channel morphology to controlling factors. However, as stated above, very little of the channel could be classified as adjustable, so the results for these sections should not be used to generalize effects elsewhere.

Pebble Counts

Pebble counts were made at 11 locations as listed in Table 2. As stated earlier, most of the surface material was greater than about 10 mm. The pebble count data are contained in electronic spreadsheet files as plots. File names are listed in Appendix II. The data are summarized in Table 4. As the Table indicates, the median or D_{50} size of the materials is quite large ranging from 72 mm up to 143 mm, or in the range of cobbles.

FIGURE 2

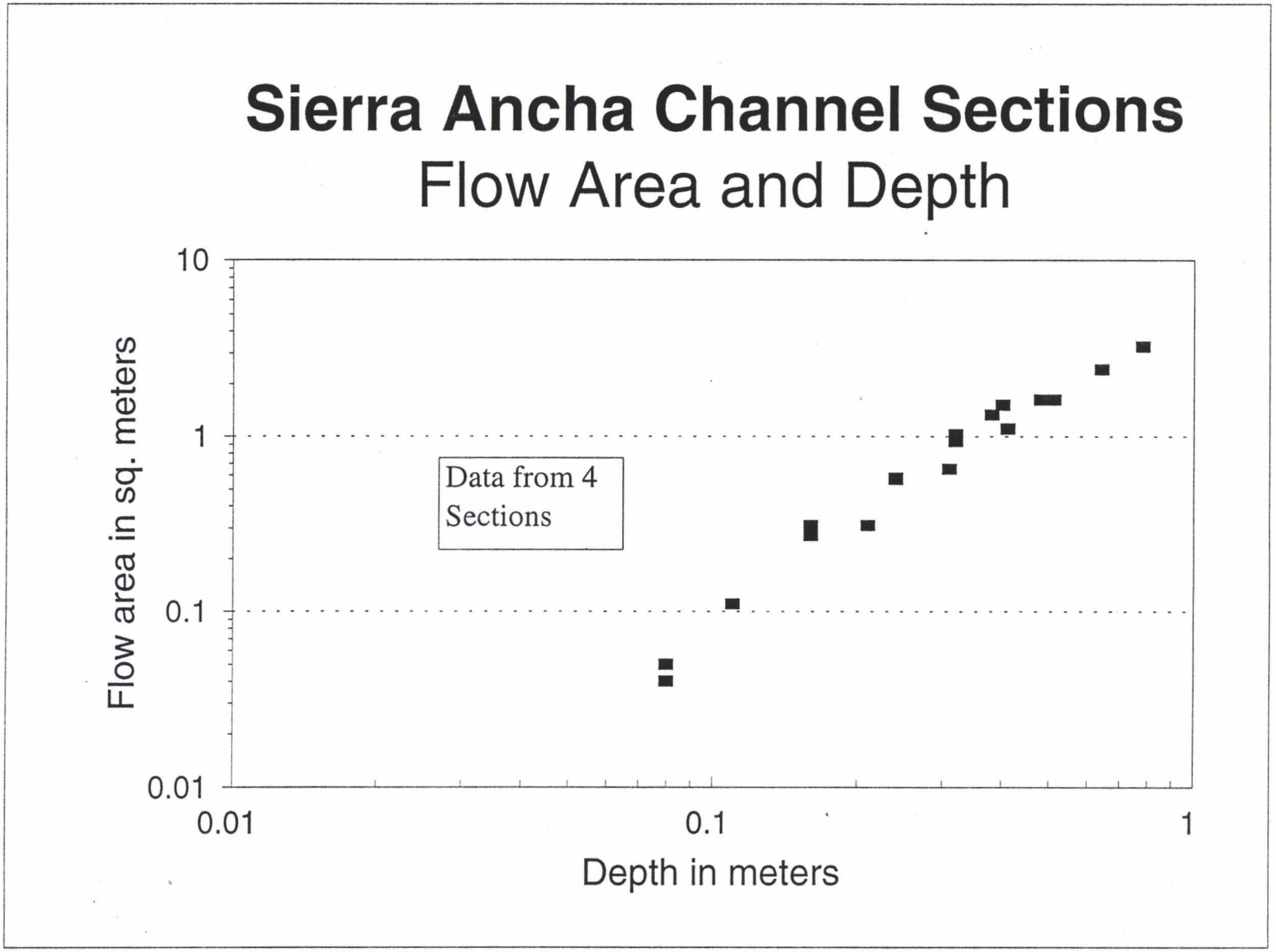

Sierra Ancha Channel Sections
Flow Area and Depth
Flow area in sq. meters
10
1
0.1
0.01
Data from 4
Sections
0.01
0.1
1
Depth in meters

Table 3. Parameters for Sierra Ancha Channel Relationships in the Form $Y = a X^b$

Relationship Y - X	Coefficient a	Exponent b	R^2
Area - Depth	6.79	1.852	0.967
Width - Depth	9.47	0.662	0.750
Width - Area	4.82	0.375	0.855
Hyd. Depth - Area	0.21	0.625	0.942

Areas, depths, and widths in meter units. Hyd. Depth is the ratio of area to width. Relationships developed from four cross sections which were measured in detail (n = 20). R^2 is the coefficient of determination and indicates the fraction of variance explained by the relationship in terms of logarithmic transforms of the Y variable.

Table 4. Pebble Count Statistics for Surface Materials

Site Identification	*D_{10}	D_{16}	D_{35}	D_{50}	D_{65}	D_{84}	D_{90}
Workman Cr. at dam	51	57	72	83	104	160	197
Workman Cr. section 1	40	45	60	72	86	121	149
Workman Cr. middle fork	49	57	81	101	125	174	205
Upper Parker Cr. at dam	58	66	82	101	135	213	295
Upper Parker Cr. section 1	46	51	68	78	91	133	167
Lower Parker Cr. at dam	34	41	61	76	101	197	240
Lower Parker Cr. section 1	55	65	92	127	159	236	296
Lower Park Cr. section 2	36	49	81	133	165	255	332
Upper Pocket Cr. above dam	46	53	77	99	124	189	220
Lower Pocket Cr. at dam	60	69	98	143	190	313	569
Lower Pocket Cr. section 1	47	53	74	94	126	169	215

*Dx represents the pebble size, D, in mm for which x percent is smaller by number

Subsurface Materials

The subsurface materials were sampled at 12 sites. A sample was taken at Workman Creek South Fork even though no surface gravel existed. The data are contained in electronic spreadsheets as graphs and are listed in Appendix III. The relevant parameters derived form the data are presented in Table 5. For the subsurface channel materials, the D_{50} ranged from 0.5 mm to 5 mm which is in the range of sand. This is in stark contrast to the D_{50} for the surface materials described above. This is not uncommon as it is recognized that larger surface materials will cover and protect the finer materials from being washed out and down the channel. The samples collected in this study indicate that is the situation found at these sites.

Table 5. Sieve Analysis Statistics for Subsurface Materials

Site Identification	*D_{10}	D_{16}	D_{35}	D_{50}	D_{65}	D_{84}	D_{90}
Workman Cr. at dam	0.41	0.57	1.31	2.33	4.00	7.49	9.07
Workman Cr. section 1	0.36	0.53	1.35	2.44	3.87	7.23	8.88
Workman Cr. middle fork	0.41	0.55	1.19	1.99	3.32	6.64	8.42
Workman Cr. south fork	0.10	0.15	0.33	0.48	0.67	1.45	2.32
Upper Parker Cr. at dam	0.51	0.71	1.81	3.16	5.19	8.36	9.72
Upper Parker Cr. section 1	0.47	0.73	2.76	5.03	6.61	9.34	10.42
Lower Parker Cr. at dam	0.26	0.32	0.61	0.97	1.62	4.52	6.61
Lower Parker Cr. section 1	0.21	0.30	0.61	1.00	1.70	5.11	7.15
Lower Parker Cr. section 2	0.26	0.34	0.76	1.51	3.07	6.88	8.60
Upper Pocket Cr. above dam	0.47	0.73	2.76	5.03	6.61	9.34	10.42
Lower Pocket Cr. at dam	0.29	0.38	0.66	0.98	1.43	2.72	3.73
Lower Pocket Cr. section 1	0.36	0.48	0.88	1.44	2.50	5.92	7.83

* Dx represents the grain size, D, in mm for which x percent is smaller by weight

Factors Affecting Channel Morphology

The in-office and in-field studies provide the information needed to characterize the factors affecting channel morphology. For this study, two sites were selected for further analyses based on availablilty of data. Only one of these sites had what could be called an adjustable channel. The two sites were Workman Creek at the Main Dam and Upper Parker Creek. Flow records at these two sites span several decades and are available, after the in-office processing, in a form amenable to analysis. Both sites share a common watershed boundary and are thus affected by precipitation events occurring over the upper elevations. In general, though, runoff in these watersheds is characterized by snowmelt or rain/snowmelt events in the late winter or early spring. Both have mixed conifer vegetation at the upper elevations with mixed hardwoods being more predominate at the lower elevation Upper Parker site. The Upper Parker Creek site is south facing and the Workman Creek site is west facing. There are 54 years of peak discharge data available at Upper Parker Creek and 41 years at Workman Creek. It should be noted, however, that the Workman Creek subwatersheds were subjected to timber harvest with detectable changes in water yield and peak flows as documented by Rich and Gottfried (1976) and Hibbert and Gottfried (1987). Upper Parker Creek was not treated.

Average and Peak Discharges

For Workman and Upper Parker Creeks, most of the runoff occurs during the months of October through May. For the 41 year period on Workman Creek available in electronic form, the avenge depth of runoff was 103 mm from a watershed area of 440 hectares. Of that amount, 90 mm occurred during the October through May period, or about 87 percent. For the Upper Parker Creek site, the average annual runoff depth from 50 years of record was 143 mm with 135 mm of that, or about 94 percent occurring in the October-May period. Based on the October-May period only (243 days), the average daily discharge was 19.6 liters per second or about 0.69 cfs for Workman Creek. For Upper Parker Creek, the average daily discharge during the same primary runoff season was 33.9 liters per second or about 1.2 cfs. Neither of these average discharges is sufficient to move the large materials in the channels.

Flow duration curves were generated for the two sites using the values obtained during the in-office part of the study. The Workman Creek site had 14,975 observations of average daily discharge in the data base, while Upper Parker Creek had 7291 observation, but 2249 or 30.8% of those were zero. Figures 3 and 4 show the flow duration curves for the two sites based on the non-zero values. The average daily flow rate for all the observations, zero and non-zero, was 14.7 liters per second for Workman Creek and 11.9 liters per second for Upper Parker Creek. Note that the Upper Parker Creek average discharge rate calculated from daily flow values is based on a different time period than that calculated from the summaries. The average discharge over the entire year is 13.8 liters per second based on the summaries at Upper Parker Creek. The average discharge for Workman Creek was the same using either method because the period of coverage is the same. Table 6 is a summary listing of the key characteristics of the two flow

duration curves shown in Figures 3 and 4. Again note that the values for Upper Parker Creek are based upon the non-zero values which only comprise 69.2% of the sample. Note that the Q_1, discharge at which the flow is exceeded on 1% of the days, at either site is less than 200 liters per second (about 7 cfs). This is another strong indication that the flows are not sufficient to move the materials under most conditions.

Table 6. Flow Duration Statistics for Workman and Upper Parker Creeks

FLOW STATISTIC	Workman Creek at Main Dam	Upper Parker Creek
n	14,975	5042 *
Average	14.9	17.20
Standard Deviation	72.40	54.60
Skew	770.00	310.00
Q maximum	3,628.00	1,275.00
Q_1 [2]	161.00	199.00
Q_5	47.00	79.50
Q_{10}	23.90	42.50
Q_{25}	9.15	12.60
Q_{50}	4.82	2.83
Q_{75}	2.83	0.67
Q_{90}	2.13	0.28
Q_{95}	1.81	0.26
Q_{99}	1.42	0.13
Q minimum	0.85	0.01

* - The data base contained 7291 observed daily flow values of which 5042 were greater than zero. Therefore, the values in this table are for only those days when flow occurred.
1 - Units are liters per second. One cfs = 28.34 liters per second.
2 - Qx is the value at which the discharge was equaled or exceeded on x percent of the days.

FIGURE 3

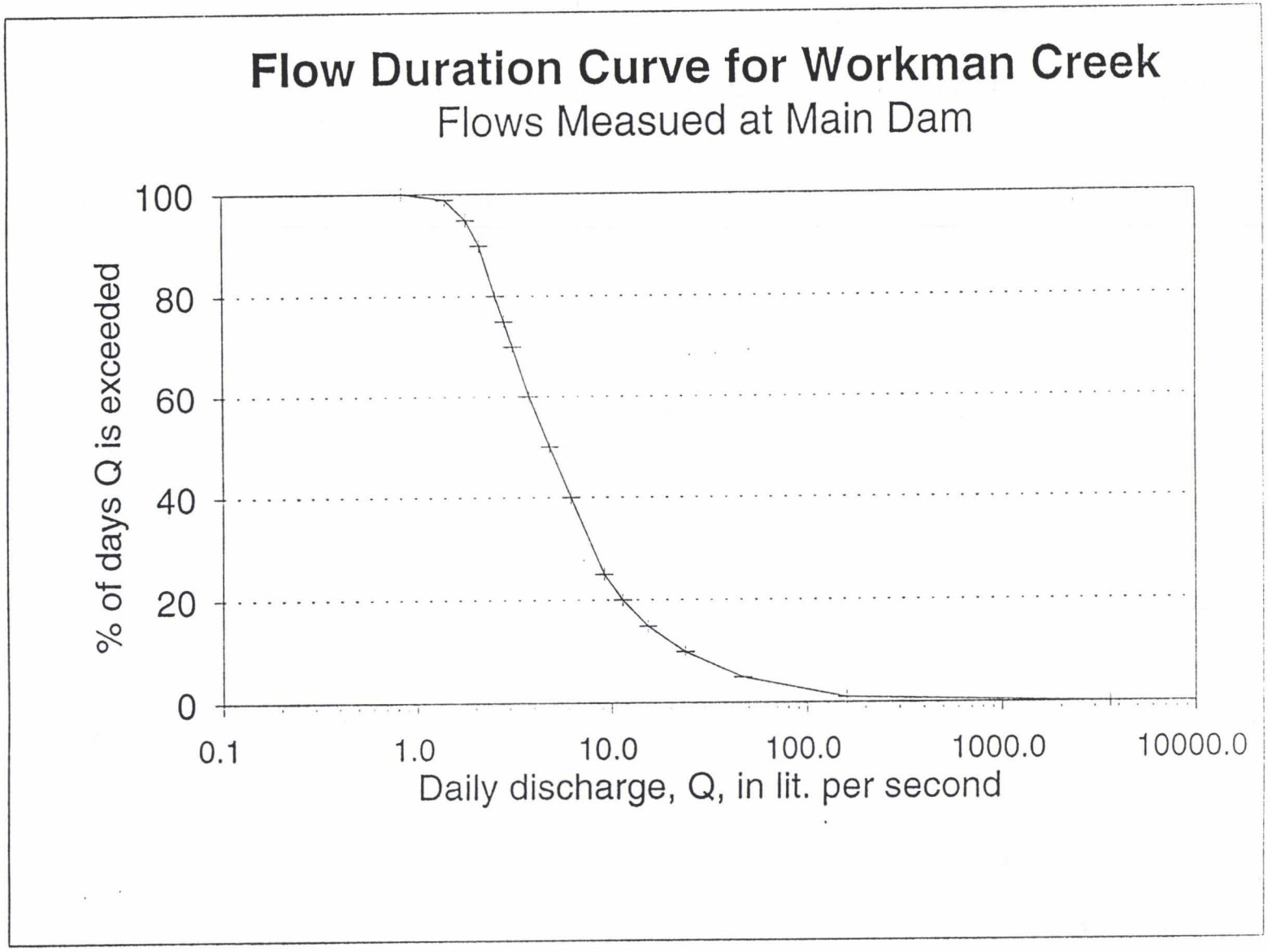
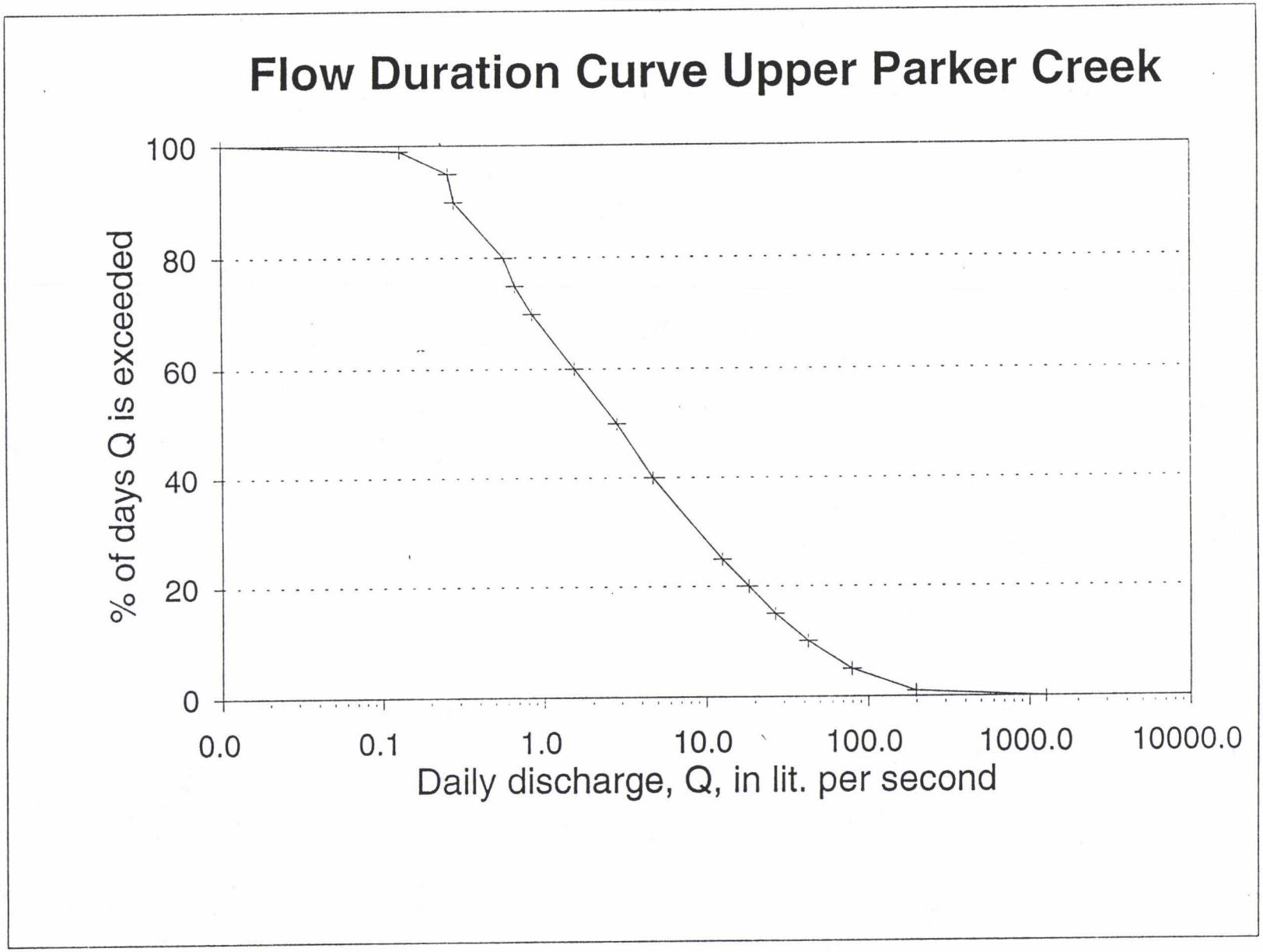

Flow Duration Curve for Workman Creek
Flows Measued at Main Dam
% of days Q is exceeded
100
80
60
40
20
0
0.1
1.0
10.0
100.0
1000.0
10000.0
Daily discharge, Q, in lit. per second

FIGURE 4


Flow Duration Curve Upper Parker Creek
% of days Q is exceeded
100
80
60
40
20
0
0.0
0.1
1.0
10.0
100.0
1000.0
10000.0
Daily discharge, Q, in lit. per second

Peak flows do generate enough energy to move the materials found in the channels. Annual maximum instantaneous discharge rates for all five gaging sites (not the Workman Creek subwatersheds) are listed on the electronic summary sheets listed in Appendix I. Data from those sheets were extracted to produce Table 7 which lists the peak flows from Workman and Upper Parker Creeks. The peak flows have skewed distributions which implies a log transformation is in order. However, when the transformation is applied to the Upper Parker Creek flows, the skew essentially reverses sign. The log transformation on the Workman Creek data removes the skew implying a log-normal distribution. If the skew is ignored, the 1% chance (100 year return period) discharge rates for the two sites can be calculated from the log-normal statistics as 17.6 cubic meters per second (cms) (621 cfs) and 16.3 cms (575 cfs) for Workman Creek and Upper Parker Creek, respectively. These calculated discharges are much higher than anything observed in the record which indicates that the log-normal distribution may not be the best method for estimating the rare runoff event from the data. About 7 or 8 annual peak discharges at each site exceed a threshold of between 90 and 100 cfs (2.55 and 2.83 cms) which is about +1 standard deviations from the mean. Discharges this high will move materials in the channels.

Estimating the Threshold Discharge

Conceptual and Statistical Development

There are a number of methods for estimating incipient motion thresholds for a specified sediment particle size. The standard approach for sand bed streams is to use a Shields' (1936) parameter to calculate shear stress required to move the particle then use channel characteristics to calculate a discharge which would move such a particle, i.e. apply the correct amount of shear stress. The problem with this approach in gravel bed rivers is the large spread in grain sizes, from sand to boulders, and the difficulties in trying to determine the correct hydraulics in a rough bed channel. As an alternative to the shear threshold criteria, Bathurst (1987) proposed a critical unit discharge approach first presented by Schoklitch (1962). He applied his approach to data collected from the Roaring River in Rocky Mountain National Park and proposed that the critical unit discharge could be found from:

$$q_c = 0.15\ g^{0.5}\ D^{1.5}\ S^{-1.12} \qquad (7)$$

where q_c is critical water discharge, g is the acceleration of gravity, D is particle size, and S is slope. The units of q_c will be in cms if g is 9.81 m/sec/sec and D is in meters. Bathurst furthered this approach by suggesting that the critical discharge for an individual grain size, q_{ci} in cms per meter of width would be related to the individual grain size D_i, in mm, as:

$$q_{ci} = a\ D_i^{\ b} \qquad (8)$$

where a and b are parameters which may be site specific. Bathurst (1987) suggested that the parameter b (exponent) may be a function of the bed surface material distribution as:

$$b = 1.5\ (D_{84}/D_{16})^{-1} \qquad (9)$$

Table 7. Peak Discharge Values for Workman Creek at the Main Dam and Upper Parker Creek. Discharges are in cubic feet per second

YEAR	WORKMAN CREEK MAIN DAM		UPPER PARKER CREEK	
	DATE	PEAK Q	DATE	PEAK Q
1934			8/31	0.57
1935			3/13	14.29
1936			2/16	28.42
1937			2/7	133.03
1938			3/3	116.59
1939	12/15	51.78	3/16	4.88
1940	2/1	5.18	2/1	17.12
1941	3/14	77.42	3/14	88.46
1942	11/13	2.87	1/12	5.74
1943	3/5	18.80	3/5	31.37
1044	4/5	5.58	3/12	11.78
1945	4/20	8.75	3/16	10.82
1946	9/19	27.93	12/23 *	**270.00**
1947	11/24	10.74	12/27	29.07
1948	3/30	1.64	3/23	2.51
1949	12/27	20.80	1/13	57.75
1950	2/27	6.64	2/27	33.73
1951	8/28	98.87	8/29	140.87
1952	1/18	117.99	12/31	61.89
1953	3/10	4.01	3/8	13.06
1954	3/23	130.56	3/23	68.36
1955	8/19	10.29	8.19	157.22
1956	1/28	2.06	12/2	26.81
1957	1/10	74.59	1/10	33.11
1958	3/22	74.59	3/22	37.55
1959	8/19	16.70	8/19	26.09
1960	12/24	16.70	8/19	26.09
1961	7/19	4.66	3/31	2.19
1962	4/5	9.26	3/26	10.80

Table 7 (continued)				
1963	2/10	20.29	8/31	117.10
1964	3/30	2.87	3/29	5.89
1965	1/7	23.77	1/7	62.59
1966	12/30	131.92	12/30	58.84
1967	12/7	78.51	12/30	43.39
1968	2/9	15.92	2/9	26.63
1969	1/25	73.20	1/15	36.47
1970	9/5	235.83	9/5	129.90
1971	9/30	6.46	9/30	21.82
1972	12/26	13.50	10/1	5.59
1973	10/7	**289.01**		
1974	8/4	23.72		
1975	4/15	12.33		
1976	2/9	67.75		
1977	8/19	6.55	1/22	5.59
1978	3/2	187.91	3/2	85.51
1979	12/18	203.83	1/17	63.90
1980			1/30	91.60
1986			2/16	91.60
1987			11/18	4.50
1988			2/3	36.00
1989			2/5	3.50
1990			8/15	3.70
1991			3/1	68.00
1992			2/13	32.00

STATISTIC	ORIGINAL	LOG 10**	STATISTIC	ORIGINAL	LOG 10
Mean	53.80	1.353	Mean	48.80	1.406
Std. Dev	70.18	0.618	Std. Dev.	52.11	0.581
Skew	1.83	0.062	Skew	2.03	-0.674
Max	289.01	2.461	Max	270.00	2.431
Min	1.64	0.215	Min	0.57	-0.244
Med	20.29	1.307	Med	32.56	1.513

* This maximum discharge was taken from USGS records. The peak in USFS files was 56.93 on 9/19. There was a high flow at Workman Cr. On 12/23, but not the maximum. The high flow on Lower Parker Cr. was on 9/18.
** Log base 10 transformed data

where D_{84} and D_{16} are the sizes at which 84% and 16%, respectively, of the bed materials are smaller. Bathurst and Ward (in preparation) expand upon this work by adding data from several new sources including the information from the Water Division 1 reserved rights case. In all, 12 new sets of data were added to the 4 sets originally used by Bathurst (1987). Each set was screened before Eqn. (8) was fit to the data. The results of those fits are presented in Table 8 along with the source of the data. The b coefficients are related to the ratio D_{84}/D_{16}, the gradation coefficient (or its theoretical equivalent $[D_{84}/D_{50}]^2$), as shown in Figure 5. The method by which the unit width discharge has some bearing on the value of b. If a fixed width is assumed, either fixed by bank constraints or taken as the avenge width of the flows sampled, then the data in Figure 5 can be represented by:

$$b = 1.39\ (D_{84}/D_{16})^{-1} \qquad (10)$$

If the width varies at the site, then the resultant form of Eqn. (9) is:

$$b = 1.60\ (D_{84}/D_{16})^{-1} \qquad (11)$$

On average, Eqns. (10) and (11) are very close to Eqn. (9) proposed by Bathurst (1987) which support the original concept. The data also lent themselves to directly determining the q_{ci} from the variables of D and S across all of the data. For the sample size of n = 307, the resultant equation was:

$$q_{ci} = 10^{(-1.208 - 0.064\ G)}\ D_i^{0.396}\ S^{-0.229} \qquad (12)$$

where G is the gradation taken as (D_{84}/D_{16}) if available or $(D_{84}/D_{50})^2$ if not, and D_i is in mm. The R^2 value for this equation based on the log-transformed linear equation was 0.717. Note that in Eqn. (12) the gradation modifies the coefficient and not the exponent.

Table 8. Derived b and gradation coefficients for selected coarse bed streams

Location	Gradation G	b Coefficient	Reference
Goose Creek #1 *	4.16	0.492	Nankervis (1004)
Goose Creek #2	2.66	0.357	Nankervis (1994)
Goose Creek #4	3.21	0.240	Nankervis (1994)
Little Beaver Creek	6.09	0.469	Nankervis (1994)
Left Hand Creek at Gage	4.18	0.476	Nankervis (1994)
Left Hand Creek above Gage	4.18	0.280	Nankervis (1994)
Pitzbach, Austria	2.50	0.500	Inpasihardjo (1992)

Table 8 (Continued)			
Roaring River Lower 1	8.68	0.219	Bathurst (1987)
Roaring River Lower 2	4.88	0.241	Bathurst (1987)
Roaring River Lower 3	4.60	0.199	Bathurst (1987)
Roaring River Upper	4.37	0.378	Bathurst (1987)
South Fork Cache la Poudre River	4.81	0.575	Nankervis (1994)
Sagehen Creek, California	3.95	0.401	Andrews (1994)
Squaw Creek, Montana	3.71	0.270	Bunte (1990)
Upper Trap Creek	7.28	0.266	Nankervis (1994)

* All sites in Colorado except as noted

Application

Eqn. (12) was applied to the two sites in the Sierra Ancha watersheds where adjustable channels were noted, Lower Parker Creek and Lower Pocket Creek. The critical size, D_i, was taken as D_{50}. The variables and results of the computations are presented below:

Lower Parker Creek -

$D_{16} = 51$ mm $\quad D_{50} = 109$ mm $\quad D_{84} = 228$ mm

$G = 4.47$ $\quad S = 0.03$ (surveyed in field) $\quad q_{ci} = 0.694$ cms/m

The bank to bank channel width at this site is 6.1 meters. Therefore, the total critical discharge for the D_{50} size is 4.23 cms. The maximum observed peak discharge at this site is 4.88 cms.

Lower Pocket Creek -

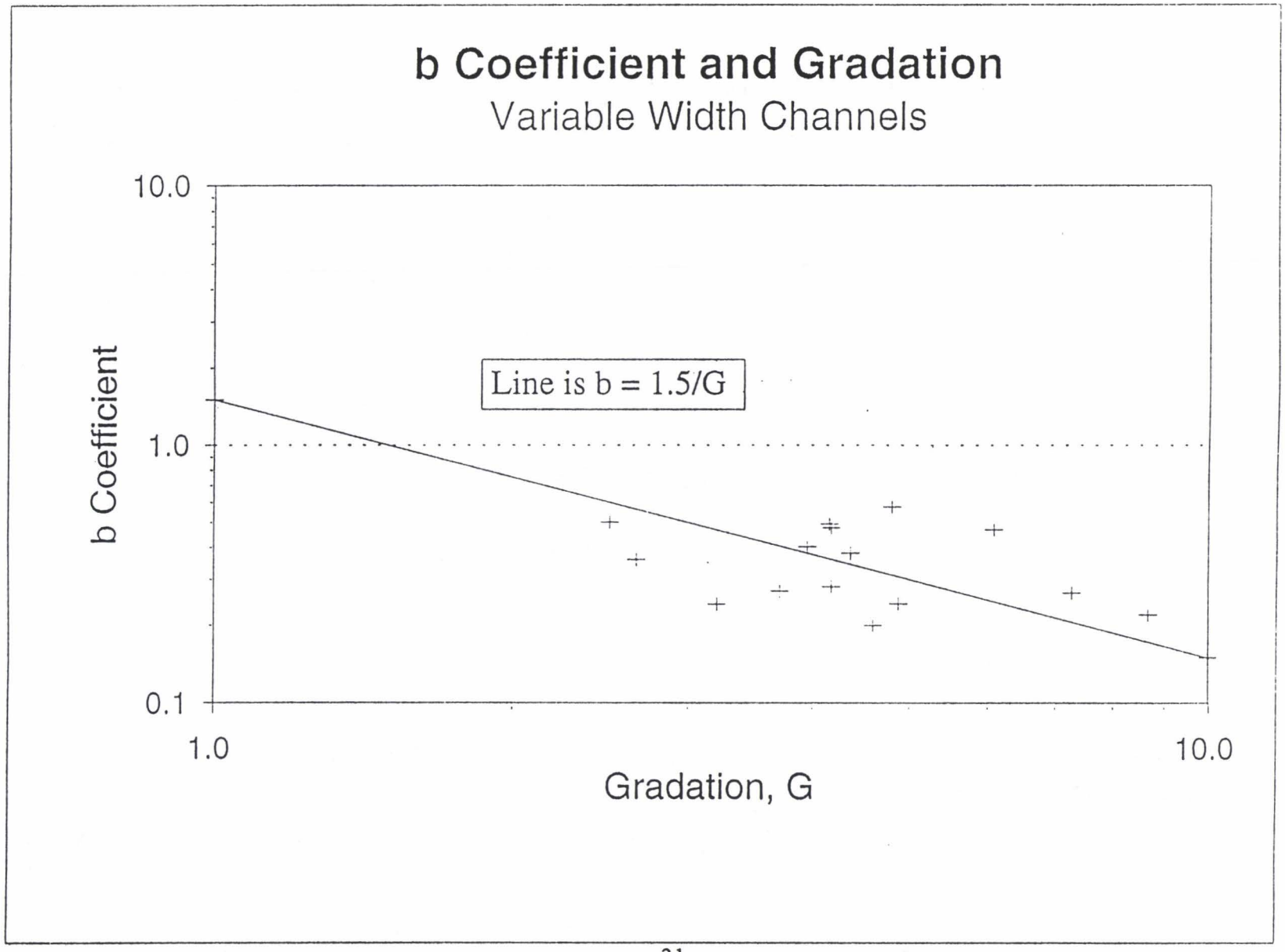
$D_{16} = 60$ mm $\quad D_{50} = 116$ mm $\quad D_{84} = 230$ mm

$G = 3.83$ $\quad S = 0.02$ $\quad q_{ci} = 0.567$cms/m

The bank to bank channel width at this site is 5.5 meters. Therefore, the total critical discharge for the D_{50} size is 3.11 cms. The maximum observed peak discharge at this site is 2.25 cms.

The computations above suggest that the peak discharges recorded in the channels are rarely able to move sizes near the D_{50} let alone some of the sizes measured in the stream. This disparity may be caused by a lack of understanding about the critical discharge process. It should be noted that the streams from which Eqn. (12) was derived are all perennial. The streams in the Sierra Ancha watershed are much more flashy and have long periods of zero flow. The high intensity peak flows in these channels may have certain energy advantages over flow in perennial streams which have longer periods of rise to peak. It is encouraging, however, to note that Eqn. (12) does give values near those observed in the field. It should also be noted that there have been long periods when flow record were not collected at these two stations, so larger flows may have occurred but were missed.

FIGURE 5


b Coefficient and Gradation
Variable Width Channels
10.0
1.0
0.1
b Coefficient
Line is b = 1.5/G
1.0
10.0
Gradation, G

SUMMARY AND CONCLUSIONS

The original goal of this study was to study selected watersheds in Arizona to establish effective discharge at historical and existing stream gaging stations. Upland watersheds were selected to determine if there was a relation between channel morphology and streamflow on watershed less than 25 square kilometers in area. The watersheds in the Sierra Ancha Experimental Watershed were chosen because they had long flow records dating back into the 1930's and they represented a common type of semi-arid and arid watershed found in the southwest. It was quickly observed that watersheds of this size do not have channels which are easily adjustable for several reasons including the preponderance of bedrock controlled channels, large alluvial materials in and on the bed of the channel, high flows which are of only a short duration, low flows most of the rest of the year, and large organic debris which helps anchor the materials which do move in relatively stable positions. In general, the type of watershed studied in this project should not be classified as having an extensive or important amount of adjustable channel length. Investigations of adjustable channels should be focussed on those perennial streams which carry significant volumes of water necessary to move the materials present.

During this study, a large body of data was gathered, collated, converted to electronic form, and analyzed. These data should be useful in future studies related to water yields, flood flows, land use effects, and sediment transport analyses. The updated data for Upper Parker Creek is a new addition which has not yet been analyzed to determine the water yield characteristics of that watershed. Better estimates of yield from upland watersheds such as Parker Creek and Pocket Creek will become more important as greater pressures are placed upon water resources in the west.

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APPENDIX I

File Names of Summary Runoff Records for the Sierra Ancha Watersheds

Contents	File Name
Workman Creek, Main Dam	WKCRMDRO.WQ1
Upper Parker Creek	UPPARKRO.WQ1
Lower Parker Creek	LOPARKRO.WQ1
Upper Pocket Creek	UPPOCKRO.WQ1
Lower Pocket Creek	LOPOCKRO.WQ1

Note: Files were saved using Quattro Pro® for DOS format and are located in an envelope on the back inside cover.

APPENDIX II

File Names of Pebble Count Information

Contents	File Name
Workman Cr. at dam (main dam)	WKMDMPEB.WQ1
Workman Cr. section 1	WKMMFPEB.WQ1
Workman Cr. middle fork	WKMS1PEB.WQ1
Upper Parker Cr. at dam	UPRDMPEB.WQ1
Upper Parker Cr. section 1	UPRS1PEB.WQ1
Lower Parker Cr. at dam	LPRDMPEB.WQ1
Lower Parker Cr. section 1	LPRS1PEB.WQ1
Lower Parker Cr. section 2	LPRS2PEB.WQ1
Upper Pocket Cr. above dam	UPTDMPEB.WQ1
Lower Pocket Cr. at dam	UPTDMPEB.WQ1
Lower Pocket Cr. section 1	LPTS1PEB.WQ1

Note: Files were saved using Quattro Pro® for DOS format and are located in an envelope on the back inside cover.

APPENDIX III

File Names of Subsurface Material Sieve Analyses

Contents	File Name
Workman Cr. at dam (main dam)	SWRKMMND.WQ1
Workman Cr. section 1	SWRKMMN1.WQ1
Workman Cr. middle fork	SWRKMMFD.WQ1
Workman Cr. south fork	SWRKMSFD.WQ1
Upper Parker Cr. at dam	SUPPARKD.WQ1
Upper Park Cr. section 1	SUPPARK1.WQ1
Lower Parker Cr. at dam	SLOPARKD.WQ1
Lower Parker Cr. section 1	SLOPARK1.WQ1
Lower Parker Cr. section 2	SLOPARK2.WQ1
Upper Pocket Cr. above dam	SUPPKT1.WQ1
Lower Pocket Cr. at dam	SLOPKTD.WQ1
Lower Pocket Cr. section 1	SLOPKT1.WQ1

Note: Files were saved in Quattro Pro® for DOS format and are located in an envelope on the back inside cover.